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# Significance of daylight in the design and construction of buildings

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Professional paper

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## Significance of daylight in the design and construction of buildings

Other than being highly significant for the comfort of people, an optimum use of daylight in buildings also contributes to a more rational use of heating and air-conditioning systems. Energy-efficient buildings containing passive and active systems for the use of solar energy would not be possible without sunlight. The issue of significance and control of lighting in existing buildings during design and construction of new ones on neighbouring plots is increasingly considered on an international scale. Laws and regulations on the use of daylight, currently applied in Europe and the USA, are compared in the paper.

### Key words:

daylight, design and construction of buildings, solar energy, energy efficiency

Stručni rad

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## Važnost dnevne svjetlosti pri projektiranju i izgradnji zgrada

Optimalno iskorištenje dnevne svjetlosti u zgradama vrlo je važno za ugodan boravak ljudi, ali doprinosi i racionalnijem korištenju sustava za grijanje i klimatizaciju. Energetski učinkovite zgrade koje sadrže pasivne i aktivne sustave za iskorištenje solarne energije ne bi bile moguće bez sunčane svjetlosti. U svijetu se sve više postavlja pitanje važnosti i kontrole rasvjete na postojećim zgradama prilikom projektiranja i izgradnje novih na susjednim parcelama. U radu je napravljena usporedba zakona i propisa iz područja dnevne svjetlosti zgrada koji su danas u primjeni u Europi i Americi.

### Ključne riječi:

dnevna svjetlost, projektiranje i izgradnja zgrada, solarna energija, energetska učinkovitost

Fachbericht

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## Bedeutung des Tageslichts beim Entwurf und Bau von Gebäuden

Die optimale Nutzung des Tageslichts in Gebäuden ist von besonderer Bedeutung für einen angenehmen Aufenthalt, trägt aber auch dem rationelleren Gebrauch von Heizungs- und Klimatisierungsanlagen bei. Energieeffiziente Gebäude, die über passive und aktive Systeme für die Verwertung von Solarenergie verfügen, wären ohne Sonnenlicht nicht möglich. Weltweit bekommt die Kontrolle von Beleuchtungssystemen bestehender Bauten beim Entwurf und Bau neuer Gebäude auf benachbarten Grundstücken immer mehr an Bedeutung. In der vorliegenden Arbeit ist ein Vergleich von Gesetzen und Regelwerken bezüglich des Tageslichts in Gebäuden, die derzeit in Europa und den USA eingesetzt werden, durchgeführt.

### Schlüsselwörter:

Tageslicht, Entwurf und Bau von Gebäuden, Solarenergie, Energieeffizienz

## 1. Introduction

If properly controlled and distributed, the daily insolation in buildings presents numerous advantages, especially with regard to visual comfort, health, productivity, and energy consumption. A successful organisation of direct insolation is a complex task due to a great number of relevant design variables, such as the appearance of building, distribution of load-bearing elements, and organisation of internal space, which are specific to each individual building. Solar light in buildings is only as good as the system of its distribution, and so a particular attention must be paid to the design in order to ensure a sufficient quantity of light, and reduce the amount of shadows and reflections [1].

However, even in case of buildings built in full accordance with principles for an optimum use of daylight, the direct insolation can be greatly reduced by construction of new buildings on neighbouring plots. For that reason, the right to sunlight has been defined, to a greater or lesser extent, by a number of European countries. Rules for construction of new buildings have been formulated in such a way that these buildings do not greatly affect the level of insolation of the existing buildings.

The direct solar radiation in interior spaces is a very positive and free resource that should be taken advantage of as much as possible. Nevertheless, some restrictions are needed as to the level of use and introduction of sun rays into the building. In fact, excessive insolation results in overheating of interior space, and hence in the need to cool such space and consume electric energy. On the other hand, an insufficient use of daylight has to be compensated by the use of artificial lighting and, once again, by consumption of electric energy. Thus an optimum solution must be sought so that an unnecessary consumption of electric energy, and hence additional cost, is reduced to minimum.

Due to complexity of the issue of daily insolation, various tools have been developed so that architects and town planners can conceive best quality solutions for the newly designed buildings, without harming the existing neighbouring buildings. Traditional tools include scale models, heuristics, design guidelines, and case studies [2]. Such tools are presently declining in popularity due to development of computer programs that enable very complex and accurate analysis of daily insolation. Some of these programs are now standardly used in space planning and building permit procurement procedures.

## 2. Effect of natural lighting on people

Humans are influenced by daily sunlight both directly and indirectly: direct effects are caused by chemical changes in human tissue due to absorption of light, while indirect effects concern regulation of basic biological functions and production of hormones, as related to exposure to sun rays. That is why it is highly important to pay proper attention to natural lighting already during the building design process, in order to improve the health, level of satisfaction, and productivity of people.

Many studies have been made about positive effects of daily insolation on human beings [3].

Natural sunlight is generally known to have a highly positive effect in the treatment of skin diseases. Daylight contains an appropriate quantity of UV radiation that enables proper functioning of skin. The exposure to UV radiation results in the manufacture of vitamin D in skin, which is of crucial significance for metabolic functions, including absorption of calcium and phosphorus [4].

Daylight eliminates noise and vibrations of electric sources of light, and constitutes the best-quality lighting in working and living environments. These comprehensive studies have also revealed that persons living and working in environments without windows are more withdrawn, indecisive, and imbalanced. In such environments devoid of daylight, people are less interested in their work [5].

The design of spaces and urban assemblies where it would be able to balance the lighting, reflection and quantity of insolation over the entire year is a real challenge, but also the problem architects and town planners are faced with on the daily basis when designing new buildings. Many computer programs, developed to resolve this problem, are capable of making detailed solar analyses of lighting over a period of one year, based on three-dimensional model of a given environment/building. Such computer programs are used in the initial phase of design when dimensions of the building are not fully defined, or in case of renewal of façade walls of existing buildings.

The sunlight and shadows influence people and their use of open spaces throughout the day, and during the entire year. Open-space activities may be increased due to the action of sun rays. Direct insolation improves architectural properties of a building as a whole and also of its segments, such as stained-glass windows and relief details on historic buildings.

## 3. Legislation

During construction of new or renovation of existing buildings, an optimum use must be made of direct insolation to make the above mentioned economic savings during the use of the building. In addition, it is advisable, and in many countries specified by law, to take into account the influence of the project on neighbouring buildings. Thus in some countries, including the United Kingdom, the "right of light" has been specified in national regulations. According to this right, new buildings can not be built if they block direct access to sun rays to the existing buildings.

### 3.1. United Kingdom

In the UK, the significance of natural lighting was recognised for the first time in 1832 when appropriate provisions were introduced in the scope of the Prescription Act [6]. According to this Act, each owner is guaranteed the right to light after twenty years of existence of a residential building, i.e. after thirty years of existence of an office building. This Act protects the rights

of each resident with respect to inadequate construction on neighbouring plots that would prevent direct insolation.

The law on the right to light was revised on 16 July 1959 when the "Right of light Act, 1959 was passed [7]. This modification has clearly defined the "Rule 45" which has become an integral part of all local bylaws and laws on construction in the United Kingdom. According to this rule, the construction is permitted until an imaginary line placed at an angle of 45° with respect to the existing wall from the centre of the neighbour's closest window (Figure 1). This rule could also be applied only in case the existing building has been at the same position for an appropriate number of years. In this respect, the limit for residential buildings was changed from 20 to 27 years, while it remained the same, i.e. 30 years, for office buildings.

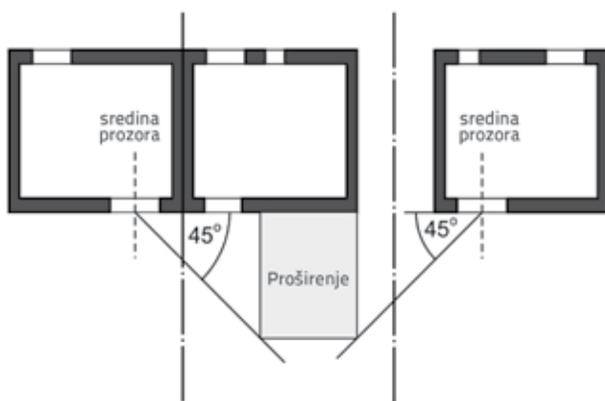


Figure 1. Construction rule "45"

Although today the "Rule 45" is no longer officially in force, it is still often used for settling out-of-court disputes in the United Kingdom, simply because it can easily be implemented. According to latest legal modifications introduced in 1990 by means of the Town and Country Planning Act 1990, Section 237 [8], the principle of "50:50" has been adopted as an official rule for protection of the right to light. This rule for measuring the level of light implies calculation of the percentage of the room's area that can benefit from adequate lighting. The calculation is conducted for a working area that is 85 cm away from the floor level. It is considered that a point receives a sufficient quantity of light if it receives 0.2 percent of the external intensity of light. Therefore, this process is considered disrupted, and the basic right to light is violated, if less than 50 percent of the working area receives less than 0.2 percent of the external intensity of light. However, as of 2010, some bigger cities have succeeded in easing provisions of the existing law in cases when a newly constructed building is considered to be of significant social or economic benefit to the local community.

### 3.2. Poland

In compliance with the construction law of the Republic of Poland adopted on 7 July 1994 [9], the Ministry of Infrastructure has passed the "Byelaw on construction with technical

requirements for buildings" [10]. Rules for construction of new buildings, specifically pertaining to the use of direct sunlight by buildings, are defined more closely in Section 2 "Lighting and sunlight", Paragraph 60, of this Byelaw.

According to the Byelaw, public buildings such as kindergartens, hospitals, and schools must have a minimum of three hours of direct insolation during the equinox, on 21 March or 21 September, in the period from 8 a.m. to 4 p.m. In case of residential buildings, direct insolation of the living room must be ensured for at least 3 hours on the equinoctial days, in the period from 7 a.m. to 5 p.m.

Exceptions can be made for buildings located in the centre of the cities. During construction of new buildings, care must be taken that neighbouring building get fifty percent less insolation, i.e. 1.5 hours on equinoctial days. In case of residential buildings, these requirements would have to be met only for apartments with more than one bedroom.

Polish regulations do not specify computer programs to be used for this kind of solar analysis. An appropriate example of the solar analysis made in Poland is the town of Szczecin where the analysis was made by the design office "W+architekci" using the computer program "SketchUp" (Figure 2), prepared for 21 September, for the period from 7 a.m. to 5 p.m. [11].

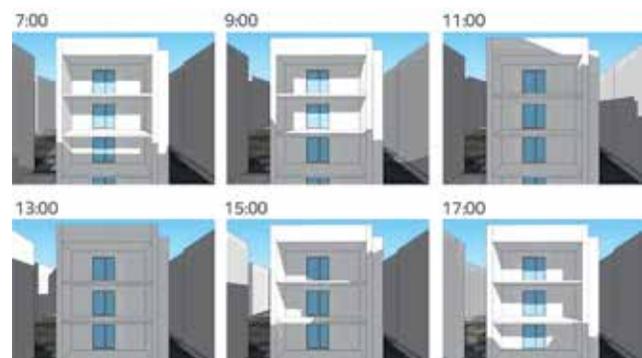


Figure 2. Solar analysis of a building in Szczecin, Poland

### 3.3. USA

In the USA, there are no laws, either on the federal level, or on the level of individual states, that would regulate construction of new buildings, and influence of their shadows on the existing buildings. This area is in fact regulated by byelaws and laws passed on the local or municipal level. However, here the attention is paid only to the protection of open spaces, historic and cultural resources, and natural areas, against shadows of newly constructed buildings.

The Department of Energy [12] acting in the scope of the US Government is inter area concerned with problems related to shadows created by newly designed buildings. This Department of Energy provides recommendations for the construction, and offers computer programs for analysing the influence of sun and shadows. A free Legacy Open Studio plug-in for the computer program SketchUp can be found on their website [13].

### 3.3.1. New York

The rules on acceptable shadows occurring during construction of new buildings are defined in Chapter 8 (Shadows) of the Code of the Mayor’s Office for Environmental Coordination of the City of New York [14]. This document contains provisions aimed at preserving the existing insolation of public spaces, parks and significant buildings. According to this Code, the influence of shadows has to be analysed during the construction work only if new buildings are more than 15 m higher than the existing ones, or if parts added to existing buildings are higher than 15 metres. In case of intervention on a building situated on the side opposite to the spaces that are considered significant for protection, then the analysis of the influence of shadows must be made regardless of the change in height.

In cases when shadows have to be analysed, the work starts with preliminary assessment (Figure 3) in order to determine whether the shadow of the building can reach sensitive spaces in its surroundings during the entire year. The preliminary

assessment implies consultation of the layout plan so as to identify the spaces surrounding the newly planned building that can be actually attained by shadows. The limit of this area is situated at the end of the longest shadow that can be created by the building during the entire year, for the period of winter solstice on 21 December. It is considered that this shadow will be 4.2 times greater than the height of the future building. As New York is situated in the Northern Hemisphere, a triangular part of the area will constantly be insulated. A part to be shadowed is situated from  $-108^{\circ}$  to  $108^{\circ}$ , viewed from the north direction.

The next stage of verification, if needed, implies a detailed solar analysis using an appropriate computer program such as: Sketchup, Autodesk’s AutoCAD, 3ds Max, AutoDesSys’ FormZ, and Bonzai3d. According to the Code, a whole day analyses must be made for: 21 June, 6 May, 21 March, and 21 December. The analysis has to be made for the period that starts 1.5 hours after the sunrise and lasts until 1.5 hours prior to sunset. This analysis is formed of two parts, the first being the solar analysis on the layout plan (Figure 4), while the second analysis



Figure 3. Preliminary assessment of shadows, [14]



Figure 4. Shadow of the future building analysed on the layout plan, [14]



Figure 5. Shadow of the future building analysed on the 3D model of the site, [14]

may imply an extremely detailed analysis using the 3D model of the entire area (Figure 5).

The approval for construction work can be obtained if the detailed analysis shows that the shadow does not cover critical areas for more than 10 minutes. If this is not the case, a project correction must be made.

### 3.3.2. San Francisco

The Code of the San Francisco Planning Department is yet another interesting example from the USA about regulations concerning influence of shadows of newly built buildings on the existing ones [15]. Detailed rules which are related, just like in New York, solely to the protection of public surfaces, parks and cultural & historic buildings and spaces, are presented in Chapter III, Article III, Shadows [16]. These rules are exactly the same as those relating to New York except for the part about the time in which an area can be under shadow, which is 45 minutes in this particular case.

### 3.4. Austria

In Austrian regulations, there are no laws that would regulate construction of new buildings and influence of their shadows on existing buildings. However, in big cities, this area is regulated by byelaws or codes. One of such codes is the Construction Code of the City of Vienna [17].

In this Code, proper care is taken not to compromise direct insolation of existing buildings or significant public spaces by construction of new buildings. According to the Code, the allowable height is regulated on the basis of simple principles developed by studying position of sun during the year in the city of Vienna. Thus it is indispensable to ensure that newly constructed buildings do not block the sunlight, by their average shadow, to ground-floor windows of existing buildings. This rule does not apply to buildings situated on the south side of the newly planned building. For buildings on the

north side an average 45-degree orientation of the shadow with respect to the horizontal plane is obtained according to expression (1), and a more detailed account is shown in Figure 6.b. Besides limiting the building height, these shadow orientations also define the maximum pitch of roofs of new buildings.

$$H = a + p \quad (1)$$

$$H = \frac{a}{\cos 30} + p \quad (2)$$

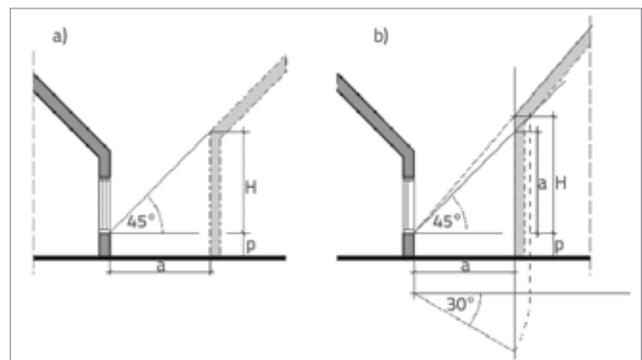


Figure 6. Diagram of allowable building height in Vienna

### 3.5. Southern and Eastern Europe

In the legislation of the Republic of Serbia, there are no strict national-level rules that would regulate the control of shadows cast on existing buildings, due to construction of new ones. Only one sentence can be found in the Byelaw on General Conditions on Plot Definition and Construction, and on the Content, Conditions and Procedure for the Delivery of the Act on Town Planning Conditions for Buildings for which Construction Permits are Delivered by District of Municipal Authorities: "a detached multistorey building must not

prevent direct insolation of another building for more than one half of total duration of direct insolation" [18]. The following sentence is included in some planning documents, such as the plan for the detailed regulation of a part of the central zone of the Vračar Municipality, Article 2.6, Conditions for Protection of Living Environment: "construction of planned buildings must not greatly reduce insolation and lighting of residential rooms of existing buildings" [19]. In this way, an emphasis is placed on the significance of daylight, but no detailed definitions and rules are given as to potential "more significant" reduction of insolation and lighting.

In Croatia, Bosnia & Herzegovina and Montenegro, there are no national-level regulations or laws that regulate construction of new buildings from the standpoint of protection of existing building against shadows of the new built ones. However, at local, municipal, and district levels, some very scarce provisions - emphasizing the need to take into account shadows - can be found in town planning documents. For instance, in the detailed development plan for Polje-Zaljevo in the Bar District, in Montenegro, the following is indicated in Section 3.6, Conditions for Development and Protection of Living Environment: "new buildings should be positioned so as not to reduce the amount of insolation and daylight to apartments situated in existing neighbouring buildings" [20].

Byelaws and other regulatory documents passed in Serbia and other countries in the region contain regulations on the distance between newly constructed buildings and existing ones, but mostly from the safety aspect, as a protection in case of building collapse. The following is specified in Article 40 of the development plan for Kukljica District in Croatia: "the building should be located within the plot in such a way that the minimum distance from the neighbouring building plot and from the access road amounts to one half of the building height" [21]. The following is indicated in Article 12 of the urban development plan for the Ravna Gora District in Croatia: "the smallest distance of the building from the neighbouring buildings amounts to  $\frac{1}{2}$  of the building height ( $h/2$ ), but shall amount to no less than 4 meters from the edge of the buildable plot" [22]. The following provisions are contained in the detailed block regulation plan for the Čukarica District in Belgrade, Serbia: "The distance between a building and a neighbouring building in open urban blocs, with respect to the façade with residential rooms, amounts to one height of the taller building. With respect to the façade with accessory rooms, this distance amounts to one half of the height of the taller building. The minimum distance for a detached building is defined with respect to the neighbouring building, and it amounts to no less than  $\frac{2}{3}$  of the height of the taller building. The distance can be reduced to  $\frac{1}{3}$  of the height of the taller building if buildings do not have windows of residential rooms, offices, and ateliers, on side facades" [23]. The following is indicated in the Byelaw on General Conditions on Plot Definition and Construction, and on the Content, Conditions and Procedure for the Delivery of the Act on Town Planning Conditions for Buildings for which Construction

Permits are Delivered by District of Municipal Authorities: "The distance between detached multistorey houses and buildings that are built in an interrupted row amounts to no less than one half of height of the taller building. This distance can be reduced to one quarter if buildings do not contain windows of residential units, ateliers and offices on side facades. This distance can be no less than 4.0 m, if one of the building walls contains openings that provide daylight" [24].

### 3.6. Classification of laws, regulations and byelaws

Laws, regulations, and byelaws regulating shadows cast on existing buildings due to construction of new buildings can be classified, according to definition method, as follows:

- Time limitation
- Intensity of light
- General

These laws, regulations, and byelaws can also be classified according to the type of facilities or spaces that are being protected:

- Laws protecting buildings only
- Laws protecting public spaces only
- Laws protecting cultural-historical buildings

Definition of solar analysis methods in laws, regulations and byelaws:

- Manual, by measurement, and by manual drawing
- Computer-aided, using various official and unofficial computer programs
- Not specified

## 4. Standards and recommendations

Various intensities of light are necessary for different types of residential and non-residential rooms. For residential rooms in which people live the daylight factor ranging from 1.6 to 3 is generally required (approximately from 80 to 150 lux), while in working and reading areas of the same room the required daylight factor varies from 3 to 6 (approximately from 150 to 300 lux) [25].

The standard SRPS U.C9.100:1963, formally regarded as a regulation, is currently applied in Serbia [26]. In the European Union, this area is regulated by the standard EN 12464 [27] which is specifically used for workplace, and is also applied for checking compliance with technical regulations. The following two building certification methods are most frequently used on an international scale: LEED US method [24] from the United States of America, and BREEAM [29] from the United Kingdom. These certifications also enable qualitative assessment of buildings from the standpoint of daylight and insolation.

In addition to these standards and regulations, all countries also have laws and regulations on energy efficiency of buildings. Numerous principles and methods, from passive

design of buildings to the use of solar collectors for water heating and electricity manufacturing, are applied in the scope of energy efficiency and bioclimatic design.

The problem with these energy efficiency standards and principles is that they do not take into account subsequent construction on neighbouring plots, which may prevent direct insolation and hence compromise the already conducted certification, or functioning of the equipment installed in the building.

## 5. Conclusion

The significance of the use of daylight and sunlight in order to achieve positive effects on the physical, physiological, and mental health of humans, is presented in the paper. All this is related to appropriate recommendations regarding the intensity of daylight in rooms, depending on activities performed in such spaces. The economic factor is considered to be highly significant for an optimum use of daylight, as it implies saving electricity that is needed for either lighting or cooling. Laws and standards relating to energy-efficiency of buildings are applied in order to achieve savings in electricity consumption. The problem that occurs in existing buildings where energy-efficiency regulations, laws and standards have been applied, lies in possible subsequent construction of new buildings on neighbouring plots, which might block direct sunlight for which thermal calculations of existing buildings were made. If solar analysis of shadow cast by new buildings is not made, then all the efforts and money invested in the implementation of the energy-efficiency principles for existing buildings might be compromised.

The solution lies in the introduction of such laws and byelaws on the construction of new buildings that define the right of owners of existing buildings to continue benefiting from the level of direct insolation they had prior to construction of

new buildings. Such laws are present to various extents and at different levels in legal documents of economically strong countries. Their common feature is that they all recognise significance of daylight and the right to the use of the amount of solar light that was guaranteed at the time the building was initially built. On the other hand, they greatly differ in protection method: some define time interval of direct insolation, some analyse intensity of light, and some provide only general guidelines thus leaving an ample space for non-compliance with regulations. In addition, great differences exist in the area of protection. In big US cities a considerable attention is paid to the "right to light" of public buildings and public spaces, to the detriment of individuals and apartments. In some European countries, much attention is paid to private buildings. Evidently, there are always exceptions, justified by socioeconomic significance of new building projects in densely populated areas. Great differences also exist in methods by which non-compliance with regulations is identified. In some cases this is checked by manual measurement, and in other cases various computer programs are used. The development of information technology has enabled widespread use of computers in the analysis of insolation and shadow propagation. The use of computer programs enables an accurate geographic positioning, and respect of climatic parameters of a given area, which ensures a highly detailed solar analysis. This kind of analysis should become a standard procedure in all countries, because of its accuracy and availability of free versions of some computer software. The fact is that laws, regulations and byelaws of this type are indispensable in all regions of the world, and especially in developing countries. Clear and accurate definition of relevant legislation is needed so as to curb down and prevent abuse. The definition of national laws is indispensable because a similar influence is exerted on all citizens, and as the of right every individual to its part of solar light has to be protected.

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